Porosity Formation and Microleakage of Composite Resins Using the Snowplow Technique

A THESIS

Presented to the Faculty of

The Air Force Postgraduate Dental School

Of the Uniformed Services University

Of the Health Sciences

In Partial Fulfillment

Of the Requirements

For the Degree of

MASTER OF SCIENCE

In Oral Biology

By

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4 May, 2012

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DEDICATION

I dedicate this to my wife Carol. You have kept me on track. Throughout our entire life together you were sensitive enough to realize when a break was required. In times of stress you have made it fun. In times of helplessness you provided guidance. In times of question you provided purpose. I do love you and will forever love you.

Four children can certainly be a challenge during anyone's life. My life seems to be fulfilled with the addition of my four children. The past two years have been filled with some good times despite the residency. I enjoyed my youngest daughter's soccer, basketball, cheer and my son's tennis and boyscouts. I am so proud of Ally's transition to college despite the difficult move during her senior year of high school. Thanks also are due to my oldest for her independence, making me feel as if she is always doing well. Awaiting their visits was always a pleasant thought to consider rather than the next exam or literature review.

Dad you have taught me through your actions how to accomplish anything in life. Your presence guides me in everything I do.

ACKNOWLEDGEMENTS

Col Kraig S. Vandewalle is the reason I am able to write this thesis. His knowledge and patience is endless. Dr. Vandewalle's interest and excitement is motivational. Dr. Vandewalle's guidance and expertise in research allows the difficult tasks to seem manageable.

I would like to thank Dr. Wen Lien. He took the time to explain the use of the Skyscan. Dr. Lien was helpful in his education and instruction in all areas of my research. He is an excellent listener and his help is appreciated. Thank you to Dr. Jeff Casey for his understanding and allowing me to stay on course. Dr. Aaron Harding was helpful in his mentoring. He continually motivated me by the example he set.

ABSTRACT

Objective: The purpose of this study was to evaluate the porosity and microleakge within a posterior composite restoration when a restorative composite (Filtek Supreme, 3M/ESPE) is placed incrementally or in bulk into a proximal-box preparation with or without light curing of a flowable-composite liner (Esthet-X Flow, Dentsply). **Methods:** Forty Class 2 slot preparations were prepared on a proximal surface of mounted 3rd molar tooth samples. A bonding agent (Optibond FL, Kerr) was placed and light cured (Bluephase 16i, Ivoclar). Ten teeth per each of four groups were restored: 1) 1-mm uncured flowable composite (snowplow technique) followed by incremental placement of composite; 2) 1-mm uncured flowable composite (snowplow technique) followed by bulk-placed composite; 3) 1-mm, cured flowable composite followed incremental placement of composite; 4) 1-mm, cured flowable composite followed by bulk-placed composite. Specimens were scanned with a microtomography unit (Skyscan 1172, Kontich) and analyzed to determine the percent porosity within the restorative composites. The mean percent porosity and standard deviation were determined per group. To evaluate microleakage, forty third molar teeth were prepared and restored as the previous samples. The teeth were kept in a laboratory oven in distilled water at 37°C for 24 hours and then thermocycled (Thermocycling Unit, Sabri) in water for 1000 cycles. The specimens were placed in a 0.5% basic fuchsin dye for 24 hours and then embedded in self-curing epoxy resin. The teeth were sectioned with a low-speed saw. Microleakage

was evaluated by placing the sections on a flat-bed scanner (Scanjet G3010 Photo Scanner, Hewlett Packard), then importing the images into a software program (Image J, NIH). The percent microleakage was determined by dividing the length of the microleakage by the length of the total bonded interface and multiplying by one hundred. The mean microleakage and standard deviation was determined per group. Data was analyzed with two-way ANOVA (alpha=0.05). **Results:** Significant differences in porosity were found between groups based on restorative composite placement ($p<0.001$) and flowable technique ($p<0.05$) with no significant interaction ($p=0.56$). The least amount of porosity was created within the proximal composite when the flowable composite was uncured (snowplow technique) and the restorative composite was placed in bulk. Significant differences in microleakage were found between groups based on restorative composite placement ($p<0.001$) and flowable technique ($p=0.03$); however, there was a significant interaction ($p<0.001$). The groups were subsequently compared using multiple unpaired t-tests (alpha=0.012). A Bonferroni correction with an alpha level of 0.025 was applied as a multiple-comparison correction because several statistical tests were performed simultaneously. **Conclusions:** The use of the snowplow technique significantly reduced microleakage when the composite was placed incrementally. The greatest amount of microleakage and porosity occurred when the flowable composite was cured prior to the incremental placement of the restorative composite. The least amount of incremental porosity formation occurred when the flowable and restorative

composites were both cured together in bulk to a depth of 5 millimeters. Perhaps the best combination of reduced porosity formation and microleakage occurred with group 2 and 4. With group 2, the initial flowable composite increment was placed and left uncured using the snowplow technique. The subsequent restorative composite was placed in bulk and light cured. With group 4, the initial flowable increment was light cured and the subsequent restorative composite was placed in bulk then light cured.

TABLE OF CONTENTS Page

LIST OF FIGURES Page

LIST OF TABLES Page

I. BACKGROUND AND LITERATURE REVIEW

A. A Brief History of Flowable and Resin Composites

Composite resin restorative materials have evolved through the years. Dental composites were first developed in the 1960s as a replacement for silicate cements and unfilled resins (Bowen et al., 1965). Early on, some of the physical properties were deficient, such as color stability (Powers et al., 1978), and wear resistance (Leinfelder et al., 1987). Over the years, properties including shade selection, wear resistance, mechanical properties (elastic modulus and coefficient of expansion), polishability and handling characteristics have improved such that now many providers consider it a principal restorative material (Eklund, 2010; Nascimento et al., 2010). Combined with dental adhesives, composites provide esthetically conservative restorations due to their ability to bond to tooth structure. However, a significant disadvantage is the marginal gap that may form due to polymerization shrinkage (Labella et al., 1999; Price et al., 2000). The popularity of conventional composite resin restorative materials sparked further research resulting in the development of flowable composites in the late 1990's (Ikeda et al., 2009; Bayne et al., 1998). Flowable composites have less filler particles giving them their unique property of reduced viscosity (Unterbrink et al., 1999). Flowable composites can be easily injected into small cavities to potentially improve adaptation to the cavity wall compared to conventional restorative composites which have a higher viscosity (Ikeda et al., 2009). The concept of placing a flowable composite beneath a

posterior composite restorative material was proposed to allow for better marginal adaptation, thereby reducing microleakage and to counter the polymerization shrinkage stress of the overlying composite resin (Braga et al., 2003; Awliya et al., 2008; Chuang et al., 2003). However, research has shown that flowable composites, in fact, shrink more than conventional composites because they have less filler content (Braga et al., 2003). Laboratory studies evaluating the efficacy of a flowable composite as a liner have been equivocal (Braga et al., 2003, Gomec et al., 2005). The advantage of the flowability of flowable composites may be offset by their dramatic increase in polymerization shrinkage.

B. Introduction of the Snowplow Technique

Various composite resin restorative placement techniques, including bulk and incremental placement, have been evaluated to minimize the polymerization shrinkage and improve the marginal adaptation of the resin-tooth interface (Ikeda et al., 2009). The snowplow technique is only briefly mentioned and not adequately explained in the literature. A study by Opdam (2003) is the only study to date that evaluates a flowable composite placed in the uncured state prior to subsequent layers of composite. The snowplow technique involves the placement of a layer of flowable composite on the pulpal floor and the gingival margin of the proximal box of a posterior composite resin restoration. However, the layer of flowable composite is not cured prior to placement of a denser-filled composite resin restorative material.

In this way, the flowable is pushed into a very thin layer, and the excess is pushed out of the preparation. Reportedly, this will leave a very thin film of the high-shrinking flowable composite in a location that may contain porosities if a denser-filled composite was used by itself (Opdam et al., 2003). The flowable and the initial heavier-filled composite layer are light cured as one increment. In contrast, a flowable composite cured in the traditional manner prior to subsequent incremental placement has been shown to increase the polymerization stress at the adhesive interface leading to possible adhesive failure (Oliveira et al., 2010; Carlos et al., 2007).

In a study by Opdam et al. (2003), composite was placed in class 1 preparations in acrylic blocks and a light microscope was used to collect data on porosity formation. Although this study was limited to visual inspection using a light microscope and class 1 preparations in acrylic blocks, the snowplow technique did result in a more homogeneous restoration as compared to more traditional placement techniques. A concern when using the snowplow technique is whether the flowable composite polymerizes adequately due to the greater thickness of the restorative materials. However, microhardness tests have shown that the polymerization is similar between the bulk fill and the incremental fill of restorations of a light shade composite (Lazarchik et al., 2007). Also, no difference was found in the depth of cure in light or dark composite restorations when restorations were polymerized from the buccal, lingual and occlusal (Amaral et al., 2002). Further studies showed that

bulk curing of a packable composite in class 2 restorations provided polymerization in increments up to 5mm in thickness (Sarrett et al., 2006) and suggested that porosity formation decreases with bulk placement of composite (Elbishari et al., 2008). In summary, class 2 preparations restored with the use of a flowable composite in the snowplow technique may offer a benefit in the placement of composite in posterior preparations.

C. Polymerization Shrinkage in Flowable and Restorative Composites

A problem of the methacrylate-based composite resins is polymerization shrinkage. The average composite resin restorative material shrinks approximately 2-6% (Feilzer et al., 1988; Kleverlaan and Feilzer, 2005). Many studies have been done to evaluate the most effective method of polymerization and composite placement (Min et al., 2010; Ferracane and Mitchem, 2003; Belevedere, 2001). The purpose of these techniques is to improve the marginal integrity. Once believed to shrink toward the light source, the direction of polymerization shrinkage has been shown to be toward the bonded surfaces (Versluis et al., 1998; Cho et al., 2002). Polymerization shrinkage has been cited to cause stresses within the tooth as opposing walls are pulled toward each other. These stresses generated by the shrinkage can overcome the weaker bond to dentinal surfaces versus the stronger bond to enamel, thereby reducing the contraction stresses within the tooth by causing a gap at the dentin/restoration interface (Feilzer et al., 1987; Kinomoto and

Torii, 1998; Kinomoto et al., 2000; Ferracane, 2008). This shrinkage and the resultant gap formation at the dentin interface have been thought to be a major cause for marginal microleakage leading to failure of composite restorations and increasing the risks of secondary caries formation; however, this theory has yet to be definitively proven (Ferracane and Mitchem, 2003; Larson, 2005; Ferracane, 2008). Alternate composite placement methods have been described with the goal of reducing the polymerization shrinkage associated with incremental placement (Deliperi and Bardwell, 2002). For example, a trans-enamel illumination technique may be used along with bulk composite placement (Belvedere, 2001). This technique involves light curing through the tooth enamel in both buccal and lingual directions and may allow the advantage of bulk placement without the disadvantages of incremental placement methods. By using the trans-enamel illumination, Sarrett et al. (2006) proposed that placement of composites with increments up to 5mm thicknesses may be considered. The bulk placement may allow greater polymerization at the tooth-composite interface and permit bonding to occur prior to the polymerization of the inner bulk portion. The enamel margins are typically less susceptible to the effects of polymerization shrinkage stress due to the much greater bond strength seen between composite and enamel than to dentin (Yazici et al., 2008). This concept may explain the results gathered by Mjör (1998), which showed that the vast majority of recurrent caries occur at the gingival margins, and suggest the need for a better bond at the dentinal/restoration interface.

D. Micro-Computed Tomography Testing of Composite

Radiography, with its film-based quality, dose efficiency, and ease of operation, has been used for the past century to provide noninvasive images that are the standard for medical and dental diagnoses. As technology advanced, radiography was steadily replaced by a new generation of digital imaging devices such as computed tomography (CT) and magnetic-resonance imaging. Among the CT scanners, micro CT has been a pioneer in the field of high-resolution computed tomography (Ritman, 2004).

The three-dimensional (3D) micro-CT image is generated via three processes: x-ray scanning, reconstruction, and volumetric rendering. During the x-ray scanning phase, a series of two-dimensional (2D) radiographs are collected from a 3D object. Each of the 2D radiographs or slices represents a projection of a 3D object in a way that its 3D structures are superimposed on top of each other and compressed onto a 2D plane. Each slice by itself is not very useful. However, as the number of 2D projections or slices increases proportionally with growing number of circumscribing scans; by using geometric reconstruction to combine all the individual 2D projections scanned at different angles, a 3D image of the original object is formed. Typically, a computer algorithm based on Filtered Back-projection and Fourier Transform techniques is applied to the iterative 2D images for the 3D reconstruction. Furthermore, modern micro-CT software allows compensation to overcome the

problems of the imprecise mathematical representation of the 3D surfaces through volume rendering techniques (Ritman, 2004).

Micro-CT allows the nondestructive, three-dimensional (3D) evaluation of materials (Sun et al., 2009). It has gained popularity in dental research and has been used in multiple studies to evaluate marginal interfaces, endodontic anatomy, remineralization, and recently porosity formation in alginate (Hamilton et al., 2010; Amano et al., 2006; Ede et al., 2008). Images can be constructed and evaluated leading to accurate qualitative results. However, no studies using this technique have been used to evaluate the porosity formation in restorative materials. Micro-CT has been used to assess microleakage at the tooth restoration interface for samples soaked for 4 hours in 50% silver nitrate (Eden et al., 2008). The disadvantage of using silver nitrate is that the size of silver particle is extremely small (~0.06 nm) in comparison with dentinal tubule or bacteria (Douglas 1989). For clinical relevance, the silver nitrate technique may be too sensitive. Zieger et al. (2009) and Sun et al. (2009) demonstrated that micro-CT could be used to analyze the spatial distribution of leakage in extracted teeth. Based on their studies, leakage was calculated as the difference that was obtained when a reconstructed image of a composite specimen after polymerization was subtracted from that of the same specimen before polymerization. Potential errors, however, could result from misalignment between the before and after images. (Zieger et al., 2009; Sun et al., 2009).

The micro-CT unit Skyscan 1172, (SkyScan Kontich, Belgium) is able to perform 3D high-resolution micro-voxel scans. The kilo voltage peak, microamperes, type of filters (e.g., aluminum or copper) and object magnification can be adjusted resulting in various image qualities. Adjustment of these parameters determines the length of scan time and resolution for each sample.

E. Microleakage Testing

Many variables affect the marginal integrity of composite resin restorations, including bond strength, depth of cure and polymerization shrinkage. Leakage at the marginal junction could lead to staining, post-operative sensitivity and possible microorganism contamination. The purpose of microleakage testing is to evaluate the fluid penetration at the restoration-tooth interface. Evaluation of microleakage is beneficial to determine the success or failure of various bonding adhesives and restorative materials. Many new materials are tested by this method to allow manufacturers and providers to evaluate and compare the performance of their products. Conner et al. (2011) used a traditional technique that involved the thermocycling of teeth followed by dye submersion, sectioning, and then visual analysis to demonstrate the inferior bond strength of self-etch sealants. The technique was also used to demonstrate that a layer of flowable composite at the gingival floor of class 2 composite restorations improved the marginal seal of the restoration (Sadeghi, 2009; Attar et al., 2004). A non-destructive alternative to

traditional microleakage testing has been accomplished through the use of micro-CT (Eden et al., 2008; Zieger et al., 2009).

F. Hardness/ Degree of Conversion

The degree of conversion (DC) of visible light-activated composite resins is vital to the success of these materials. Hardness of the external surface of the composite is not an indicator of the extent of polymerization at the internal region (O'Brien, 2002). Although the DC of the external surfaces of a light-cured composite resin can be assessed quite easily, the DC of the internal regions of the resin cannot be easily evaluated (Moore, 2008). Several factors such as the light intensity, exposure time, wavelength of light, and the light scattering within the restoration can influence the depth of cure of a resin material (Powers et al., 2006). The physical properties of a composite can be inadequate if the material is not polymerized completely.

Ferracane and Greener (1986) concluded that current light-curing techniques may produce adequate marginal integrity, although the properties of the base of these restorations may be significantly less than the properties on the surface. In contrast, Silikas et al (1986) showed that a decreased DC may be beneficial and lead to a decrease in polymerization shrinkage and reduced contraction stress. Composition of the resin also affected depth of cure (Eliades et al., 1987). Raptis et al (1979) found that differences in filler content affected compressive strengths, moduli of elasticity, water sorption, and linear coefficient of thermal expansion for four

composite resins. Smaller particle resins would take longer to cure due to increasing random light scattering (Jain, 2003). Clinically, adequate depth of cure has been proposed as one of the most important factors affecting the overall longevity and performance of composites.

II. OBJECTIVES

A. Objective Overview

The purpose of this study was to evaluate porosity formation and microleakage of flowable composite resins to dentin using the snowplow technique. Standardized class 2 slot preparations were prepared in extracted third molar teeth with the gingival margin on dentin. The adhesive bond to dentin is less predictable as compared to enamel and may provide a more robust evaluation of the use of the uncured flowable composite in the snowplow technique (Erickson et al., 2009). A flowable-composite liner (Esthet-X Flow, Dentsply, Milford, DE) was placed in the proximal box of these preparations with or without light curing it. A restorative composite (Filtek Supreme Ultra, 3M/ESPE, St. Paul, MN) was placed incrementally or in bulk into the proximal-box preparation. Porosity formation was studied first using microtomography. Subsequently, the bond formed at the gingival margin was evaluated using microleakage testing.

B. Specific Hypotheses

This study tested two specific null hypotheses as follows;

1. There is no significant difference in porosity formation when composite resin is placed incrementally or in bulk into a posterior box with or without light curing of the flowable composite resin liner

2. There is no significant difference in cervical microleakage when composite resin is placed incrementally or in bulk into a posterior box with or without light curing of the flowable composite resin liner.

III. MATERIALS AND METHODS

A. Experimental Design Overview

The materials used in this study were Esthet-X Flow, Filtek Supreme Ultra, and Optibond FL (see Table 1).

A total of 4 groups were created as seen in Table 2. Extracted human third molars were mounted in dental stone. Class 2 slot preparations were made in each of the teeth. Ten specimens were prepared per group resulting in 40 total specimens. Flowable composite was placed on the gingival floor in the proximal box. A restorative composite was then placed. Group 1: 1-mm uncured flowable composite (snowplow technique) followed by incremental placement of composite. Group 2: 1-mm uncured flowable composite (snowplow technique) followed by bulk-placed composite. Group 3: 1-mm, cured flowable composite followed by incremental placement of composite. Group 4: 1-mm, cured flowable composite followed by bulk-placed composite. The groups were evaluated using a micro-CT scanner for porosity formation. Four additional groups of specimens were prepared the same as the other groups and placed in dye for microleakage evaluation.

B. Experimental Design

Forty extracted human third molars were stored in 0.5% chloramine T and used within 6 months following extraction. The teeth were mounted in dental stone to a

level 2 mm apical to the CEJ (Figure 1A). All samples were created by one provider to minimize inter-operator differences and to ensure uniformity of fabrication. Class 2 slot preparations were prepared on a proximal surface using carbide burs and hand instruments (Figure 1B). The proximal slot preparation was extend apically 0.5 mm past the CEJ. The occlusal and proximal surfaces were flattened to allow for a standardized 5-mm occlusal-gingival, 4-mm buccal-lingual and 2-mm deep axial slot preparation. Starting from the cervical margin, increments at 1 and 3 mm were marked in the preparation using a fine mechanical pencil and then with a fine black marker. All measurements were made using an electronic digital caliper (Northern Tool, Burnsville, MN). See Figure 1C.

The preparations were etched using 37.5% phosphoric acid for 15 seconds. Etchant was rinsed for 15 seconds with an air/water syringe and air dried for 3 seconds without desiccation. A Tofflemire metal matrix band was placed around the preparation. Optibond FL (Kerr, Orange, CA) primer was applied using slight brushing motion for 15 seconds followed by air drying for 5 seconds. The Optibond FL adhesive was applied with light brushing motion for 15 seconds followed by air thinning for 3 seconds. The teeth were then light cured using a visible-light polymerization unit with an irradiance of 1600 mW/cm^2 (Bluephase 16i, Ivoclar, Amherst, NY) for 20 seconds. The adequacy of the light unit's intensity was assessed immediately prior to specimen preparation using a radiometer (LED

Radiometer, Kerr). The tip of the light guide rested on the flattened occlusal surface of the tooth.

Ten teeth per each of four groups were restored: For group 1, a 1-mm increment of Esthet–X Flow (Dentsply) flowable composite was placed but not light cured (snowplow technique) followed by a 2-mm increment of Filtek Supreme Ultra (3M ESPE) restorative composite. This combined layer was light cured for 20 seconds. Another 2mm increment of composite was placed to fill the preparation and light cured for 20 seconds. Group 2 was restored with a 1-mm increment of flowable composite (snowplow technique) that was not light cured followed by the restorative composite that was placed in bulk and cured for 40 seconds. Group 3 was restored with a 1-mm flowable composite increment that was cured for 20 seconds followed by two, 2-mm increments of the restorative composite. Each increment was cured for 20 seconds. Group 4 was restored with a cured 1-mm increment of flowable composite followed by the restorative composite that was placed in bulk and cured for 40 seconds. All composite restorations were polished with a series of Sof-Lex discs (3M ESPE). The completed specimens were stored in a laboratory oven (Model 20, GC, Chicago, IL) for 24 hours in distilled water at 37°C. Restorations were scanned with the microtomography unit (Skyscan 1172, Kontich, Belgium) and the recorded images were reconstructed (NRecon, version 1.4.4, Skyscan) into three-dimensional images. Using proprietary software (CT Analyzer, version 1.6.0.0,

Skyscan), the images were analyzed non-destructively to determine the percent porosity. See Figure 2.

To evaluate microleakage, forty extracted third molar teeth were prepared and restored similar to the previous micro-CT specimens. The teeth were kept in a laboratory oven in distilled water at 37°C for 24 hours and then thermocycled (Thermocycling Unit, Sabri, Downers Grove, IL) in water for 1000 cycles between $5 \pm 2^{o}C$ and $55 \pm 2^{o}C$, with a dwell time of 30 seconds at minimum and maximum temperatures. After thermocycling, two coats of finger-nail polish (Artistry, Ada, Mich.) were applied to the entire tooth except for a 1-mm perimeter surrounding the restoration. The specimens were placed in a 0.5% basic fuchsin dye (Spectrum Chemical, Gardena, CA) for 24 hours. After removing the specimens from the dye, the teeth were embedded in self-curing epoxy resin (Buehler, Lake Bluff, IL) and allowed to set for 24 hours. The teeth were sectioned with 3 parallel cuts in the mesial-distal direction with a low-speed saw (Isomet, Buehler). Four surfaces per tooth were analyzed (i.e., two sides of each sectioned slice). Microleakage was evaluated by scanning the sections using a flat-bed scanner (Scanjet G3010 Photo Scanner, Hewlett Packard, Palo Alto, CA), then importing the images into a software program (Image J, NIH, Bethesda, MD). The percent microleakage was determined by dividing the length of the microleakage by the length of the total bonded interface and multiplying by one hundred.

Table 1: Study Materials

Material	Type	Manufacturer	Resin	Filler
Filtek Supreme Ultra	Nano methacrylate-based composite resin	3M/ESPE, St. Paul, MN	Bis-GMA, Bis-EMA, UDMA, TEGDMA	Zirconia, Silica
Optibond FL	Three-step etch-and-rinse, methacrylate-based bonding agent	Kerr, Orange, CA	HEMA; Bis-GMA, GDMA	barium glass, fumed silicate dioxide
Esthet –X Flow	Flowable, methacrylate-based composite resin	Dentsply Caulk, Milford, DE	Bis GMA, TEGDMA	Silicate Glass
Gel Etchant	37.5% Phosphoric Acid Gel	Kerr, Orange, CA		

HEMA= hydroxyethyl methacrylate
Bis-GMA= bisphenol A glycol methacrylate
GDMA= glycol dimethacrylate
TEGDMA= triethlyene glycol dimethacrylate
UDMA= urethane dimethacrylate
Bis-EMA= ethoxylated bisphenol A methacrylate

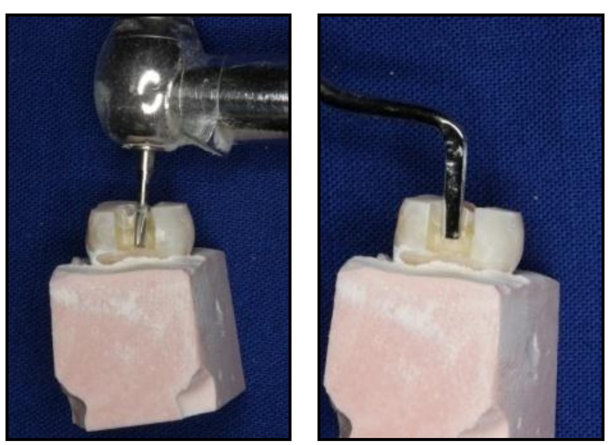
Table 2: Study Groupings

Group	Restorative Material	Bonding Agent	Placement technique / curing method
1	Esthet-X Flow Filtek Supreme Ultra	Optibond FL	Flowable Uncured Incremental restorative composite
2	Esthet- X Flow Filtek Supreme Ultra	Optibond FL	Flowable Uncured Bulk restorative composite
3	Esthet- X Flow Filtek Supreme Ultra	Optibond FL	Flowable Cured Incremental restorative composite
4	Esthet- X Flow Filtek Supreme Ultra	Optibond FL	Flowable Cured Bulk restorative composite

Figure 1: Specimens Preparation

A. Extracted 3rd molar embedded in dental stone

B. Tooth prepared using carbide bur and hand instruments



C. Class II preparation design. Incremental restoration markings at 1mm annotated using digital caliper

Figure 2: Porosity Evaluation with micro-CT

A. Skyscan micro-CT unit used to evaluate specimens

B. Micro-CT evaluation. Specimen placed on platform stage

IV. STATISTICAL MANAGEMENT OF DATA

A mean and standard deviation for percent porosity formation and microleakage was tabulated for each group. Data were analyzed with two-way ANOVA (alpha=0.05). A sample size of 10 per group provided 80% power to detect a moderate effect size of 0.455 (or approximately 0.91 standard deviation difference) between means for both main factors and for the interaction term when testing with two-way ANOVA (each with 2 levels) at the alpha level of 0.05 (NCSS PASS 2002).

V. RESULTS

Significant differences in percent porosity were found between groups based on restorative composite placement ($p<0.001$) and flowable technique ($p<0.05$) with no significant interaction ($p=0.56$). See Table 3.

Bulk filling the restorative composite into the proximal box preparations resulted in significantly less porosity formation compared to incremental filling. The snowplow technique (uncured flowable) resulted in significantly less porosity than the placement of a cured flowable increment. The least amount of porosity was created within the proximal composite when the flowable composite was uncured and the restorative composite was placed in bulk. See Figure 3.

Significant differences in microleakage were found between groups based on restorative composite placement ($p<0.001$) or flowable technique ($p=0.03$), however, there was a significant interaction ($p<0.001$). The groups were subsequently

compared using multiple unpaired t-tests. A Bonferroni correction with an alpha level of 0.012 was applied as a multiple-comparison correction because several statistical tests were performed simultaneously. See Table 4.

The use of the snowplow technique significantly reduced microleakage when the composite was placed incrementally. The greatest amount of microleakage occurred when the flowable composite was cured and the restorative composite was cured incrementally. See Figure 4.

Table 3. Mean percent porosity and standard deviation

Restorative Composite Placement	Flowable Technique	
	Uncured	Cured
Incremental	Group 1: 0.82 (0.64)	Group 3: 1.24 (0.75)
Bulk	Group 2: 0.11 (0.08)	Group 4: 0.34 (0.19)

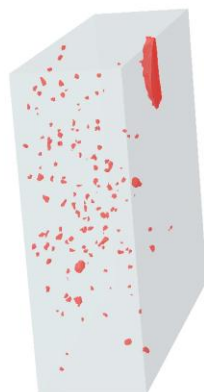
Table 4. Mean percent microleakage and standard deviation

Restorative Composite Placement	**Flowable Technique**	
	Uncured	Cured
Incremental	Group 1: 52.2 (11.9) Ab	Group 3: 75.6 (6.2) Aa
Bulk	Group 2: 43.3 (13.5) Aa	Group 4: 34.7 (6.9) Ba

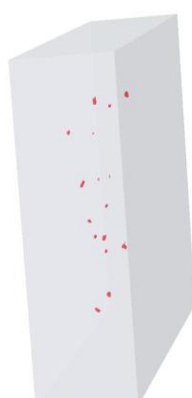
Groups with the same upper case letter per column or lower case letter per row are not significantly different (p>0.012).

Figure 3: Representative micro-CT images showing the porosity quantity and location.

A. Group 1: 1-mm uncured flowable composite (snowplow technique) followed by two, 2-mm, 20-sec-cured incremental placements of composite



B. Group 2: 1-mm uncured flowable composite (snowplow technique) followed by 40-sec curing of bulk-placed composite

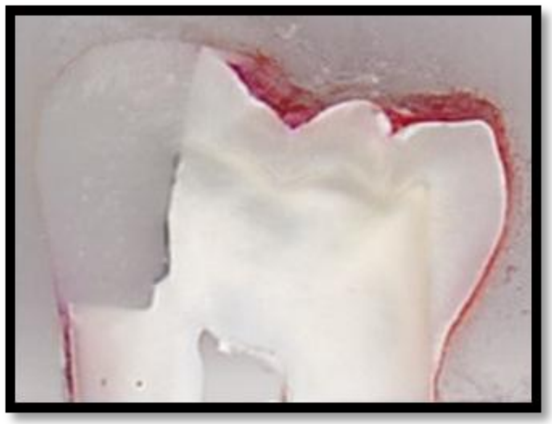


C. Group 3: 1-mm, 20-sec-cured flowable composite followed by two, 2-mm, 20-sec-cured incremental placements of composite

D. Group 4: 1-mm, 20-sec-cured flowable composite followed by 40-sec curing of bulk-placed composite

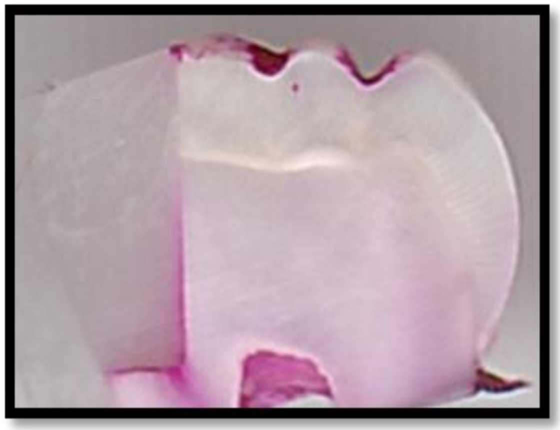
Figure 4: Representative images of microleakage from the four groups.

A. Group 1: 1-mm uncured flowable composite (snowplow technique) followed by two, 2-mm, 20-sec-cured incremental placements of composite



B. Group 2: 1-mm uncured flowable composite (snowplow technique) followed by 40-sec curing of bulk-placed composite

C. Group 3: 1-mm, 20-sec-cured flowable composite followed by two, 2-mm, 20-sec-cured incremental placements of composite



D. Group 4: 1-mm, 20-sec-cured flowable composite followed by 40-sec curing of bulk-placed composite

VI. DISCUSSION

The first null hypothesis was rejected. It stated there would be no significant difference in porosity formation when composite resin is placed incrementally or in bulk into a posterior box with or without light curing of the flowable composite resin liner.

The second null hypothesis was also rejected. It stated there would be no significant difference in microleakage when composite resin is placed incrementally or in bulk into a posterior box with or without light curing of the flowable composite resin liner.

Group 3 had the greatest amount of microleakage along the bonded interface and porosity formation between the increments (Figure 4C). The greater interfacial microleakage may be due to the combination of greater polymerization shrinkage associated with greater degree of conversion and porosity formation between the increments. Each increment of the restoration (flowable and restorative composite) was individually cured for 20 seconds each, maximizing the polymerization of each increment and the restoration. Greater polymerization could lead to increased shrinkage stress at the bonded interface. Subjectively, both Groups 2 and 3 had dramatic microleakage extending below the bonded interface toward the pulp (Figure 4B and C). With Group 3, the greater polymerization stress may have debonded the adhesive bonding agent, allowing the perfusion of dye toward the pulp. Although Group 2 had the least amount of incremental porosity formation, the

flowable and restorative composite were both cured together in bulk to a depth of 5 millimeters (Figure 3B). The large bulk contributed to decreased porosity within the mass of composite but also attenuated the light from the curing unit. Subsequently, the poorly cured cervical increment may have been susceptible to hydrolysis by the thermocycling procedure, allowing adhesive interface degradation and pervasive microleakage extending toward the pulp. Microleakage was visualized between the increments in all groups except Group 3, the cured flowable and bulk-placed composite group. Group 1 had three specimens with visual microleakage between the increments, Group 4 had four, and Group 3 had five.

Opdam et al. (2003) studied the porosities formed during various composite placement techniques. The specimens tested in the study were machined class 1 preparations in a polymethylmethacrylate block for the purpose of observing the presence or absence of voids using a 10x light microscope. Results suggested a more homogenous restoration with the flowable composite placed and left uncured (snowplow technique) followed by bulk placement of cured composite.

Various technical problems initially developed when using the micro-CT to evaluate porosity within the composite specimens. The evaluation of the different regions within the specimen volume required the flowable composite to provide radiographic contrast with the dentin and restorative composite. The flowable composite which

had the most contrast was Esthet-X Flow by Dentsply. Esthet-X Flow allowed clear visualization of the tooth-composite interface. A second problem arose when trying to scan the composite restoration and the surrounding dentin. How was the porosity of the dentin going to be distinguished from the composite-restoration interface? To resolve this problem, the scans were limited within the composite restoration. A region of interest was custom created for each specimen that was near the interface of the composite and tooth structure, but not extending past the interface into dentin or enamel. Due to the variation of the cavity preparation, this method required several regions to be drawn within each specimen. One possible problem with this technique was be the creation of different regions of interest for the different specimens. The different regions were evaluated and a percent porosity was determined, however, the percent porosity of different regions would tend to vary. Finally, a technique was utilized that created a region of interest which was slightly smaller than the composite restoration, but could be fit into each specimen without changing the volume. A region of predetermined height and diameter was selected to fit each restoration specimen allowing a consistent volume and more predictable results. A 3-D image was reconstructed allowing a visual depiction of the porosity formation.

Previous studies have utilized a microcomputed tomography scanner to image restorations. Three-dimensional images were reconstructed to determine both polymerization shrinkage and microleakage without destroying the specimens. This

alternative testing method allowed 3D visualization and quantification of potential microleakage sites, whereas traditional methods have evaluated microleakage along the plane through which the specimen was sectioned. The potential for microleakage was calculated through the measurement of gap formation at the interface (i.e., difference between the reconstructed image before and after polymerization). Microleakage data obtained through these calculated gap measurements were confirmed using traditional methods of microleakage testing. However, the teeth were not restored using a bonding agent making it less clinically significant and not comparable to our study (Sun et al., 2009; Zieger et al., 2009).

In this study, the interface between the gingival floor of the preparation and the flowable composite was initially planned to be evaluated using microtensile bond strength testing. The original proposal involved sectioning the restorations into 1mm x 1mm specimens. The small proximal slot composite restorations could not be sectioned consistently without fracturing the specimens. Therefore, the microtensile bond strength testing was abandoned and the restoration interfaces were evaluated using microleakage.

Future research is needed to evaluate the depth of cure and degree of conversion of various composites with similar placement techniques as used in this study. Also, it would be beneficial to correlate microleakage with degree of conversion and to conduct the microtomographic analysis utilizing a contrast agent.

VII. CONCLUSION

The use of the snowplow technique significantly reduced microleakage when the composite was placed incrementally. The greatest amount of microleakage and porosity occurred when the flowable composite was cured prior to the incremental placement of the restorative composite. The least amount of incremental porosity formation occurred when the flowable and restorative composites were both cured together in bulk to a depth of 5 millimeters. The best combination of reduced porosity formation and microleakage occurred with Groups 1 and 4. With Group 1, the initial flowable composite increment was placed and left uncured using the snowplow technique. The two consecutively placed two-millimeter increments were cured for 20 seconds each, allowing for adequate cervical polymerization, but not to the level of conversion as seen with Group 3. With Group 4, the initial flowable increment was light cured, but the subsequent restorative composite was placed in bulk and light cured, significantly reducing porosity and polymerization shrinkage stress.

Appendix A. Raw Data, Percent Porosity

		Total Porosity %
Group 1	T1	0.933998
	T2	2.116798
	T3	0.738443
	T4	1.222657
	T5	0.556873
	T6	1.451780
	T7	0.238028
	T8	0.741330
	T9	0.085670
	T10	0.123905
Mean		0.82095
Standard Deviation		0.64122

		Total Porosity %
Group 2	T1	0.027173
	T2	0.017330
	T3	0.122630
	T4	0.158297
	T5	0.189843
	T6	0.234433
	T7	0.015767
	T8	0.133733
	T9	0.162397
	T10	0.035247
Mean		0.10969
Standard Deviation		0.07998

		Total Porosity %
Group 3	T1	1.571653
	T2	0.030990
	T3	1.562070
	T4	0.397353
	T5	1.332907
	T6	0.266040
	T7	1.472207
	T8	1.552790
	T9	1.898473
	T10	2.305653
Mean		1.23901
Standard Deviation		0.75009

		Total Porosity %
Group 4	T1	0.170943
	T2	0.291557
	T3	0.135957
	T4	0.641540
	T5	0.565633
	T6	0.187400
	T7	0.546790
	T8	0.144697
	T9	0.355437
	T10	0.360853
Mean		0.34008
Standard Deviation		0.18834

Raw Data and Percent Microleakage

Group 1

		1			2			3			4		Mean	st dev
1	100.2	157.3	63.7	55.9	155.9	35.9	100.6	155.5	64.7	96.9	153.3	63.2	56.9	14
2	36.1	156.4	23.1	46.4	150.7	30.8	68	156.3	43.5	104.2	151.6	68.7	41.5	20
3	93.3	132.9	70.2	73.1	128.9	56.7	56.2	129.5	43.4	73.5	126.8	58	57.1	11
4	114.6	177.2	64.7	87.5	187.7	46.6	91.7	179.9	51	96.3	184.1	52.3	53.6	7.7
5	41.1	172.4	23.8	111	178.1	62.3	88.7	170.7	52	40	172.3	23.2	40.3	19.9
6	72.4	158.1	45.8	75.9	158.6	47.9	40.8	159.7	25.5	48.3	159.9	30.2	37.4	11.1
7	110.4	163.7	67.4	139.7	167.3	83.5	109.8	163.6	67.1	139.1	169.3	82.2	75.1	9
8	88.1	153.2	57.5	78.3	156	50.2	104.9	155.8	67.3	106.1	157.3	67.5	60.6	8.4
9	101.8	156.6	65	117.1	149.3	78.4	80.4	160.1	50.2	64.8	158.7	40.8	58.6	16.5
10	76.2	177	43.1	59.7	176.6	33.8	70.1	165.2	42.4	71	159.4	44.5	41	4.8
													52.2	
													11.9	

Group 2

		1			2			3			4		Mean	st dev
1	96.5	163.5	59	75.8	160	47.4	88.1	155.7	56.6	82.1	143	57.4	55.1	5.2
2	57.5	171.9	33.4	59.5	177.8	33.5	75.2	171.1	44	60.7	169.2	35.9	36.7	5
3	47	140	33.6	41.4	135.7	30.5	46.5	145	32.1	51.5	137	37.6	33.4	3
4	46.6	174.1	26.8	42	169.4	24.8	57.4	172	33.4	41.5	155	26.8	27.9	3.7
5	83.7	167.4	50	80.9	163.8	49.4	67.9	161.4	42.1	77.2	170.1	45.4	46.7	3.7
6	32.2	146	22.1	37.8	145.2	26	46.1	143	32.2	48.8	144.9	33.7	28.5	5.4
7	111.5	162.5	68.6	115.5	160.5	72	112	162.6	68.9	112.8	156.2	72.2	70.4	1.9
8	61.4	158.9	38.6	48.1	147	32.7	42.2	135.6	31.1	66.2	147.2	45	36.9	6.3
9	61.2	144.8	42.3	59.1	150.6	39.2	67.2	160.8	41.8	74.3	146.6	50.7	43.5	5
10	68.2	142.9	47.7	81.1	138.2	58.7	72.7	136.2	53.4	81.1	145.3	55.8	53.9	4.7
													43.3	
													13.5	

Group 3

	1			2			3			4			Mean	st dev
1	126.6	158.8	79.7	118	156.9	75.2	107.8	154	70	125	165.2	75.7	75.1	4
2	125.9	178.9	70.4	154.2	175	88.1	164.1	174.3	94.1	172.6	172.6	100	88.2	12.8
3	136.4	161.6	84.4	104.3	164.2	63.5	118.1	161.1	73.3	126.8	159.2	79.6	75.2	9
4	121.6	169.8	71.6	114.4	167.5	68.3	122.8	171.2	71.7	125.1	170.3	73.5	71.3	2.2
5	109.2	138.5	78.8	123.5	151.3	81.6	120.7	150.1	80.4	103.4	140.1	73.8	78.7	3.4
6	116.5	155.1	75.1	100.8	137.8	73.1	103.3	151.1	68.4	104.3	138.6	75.3	73	3.2
7	149.6	194.6	76.9	133.3	188.8	70.6	116.4	182.6	63.7	117.3	191.4	61.3	68.1	7
8	113.8	159.8	71.2	117.5	163.1	72	116.3	163	71.3	106.2	160.5	66.2	70.2	2.7
9	126.1	166.5	75.7	118.5	167.7	70.7	125.8	164.6	76.4	166.7	166.7	100	80.7	13.1
													75.6	
													6.2	

Group 4

	1			2			3			4			Mean	st dev
1	61	144.5	42.2	53.5	148.2	36.1	43	150.4	28.6	64.9	150.6	43.1	37.5	6.7
2	73.2	142.8	51.3	39	141.3	27.6	36.2	136	26.6	40	148.1	27	33.1	12.1
3	39.3	156.5	25.1	60.4	156.2	38.7	62.4	153.3	40.7	13	157.6	8.2	28.2	15
4	84.4	158.1	53.4	86.3	155.4	55.5	84.2	156.1	53.9	10	147.7	6.8	42.4	23.8
5	71.1	139.4	51	74.4	145.4	51.2	10.8	137.4	7.9	95.7	145	66	44	25.1
6	72.5	150.2	48.3	79.7	152.7	52.2	56.5	133.1	42.4	0	143.4	0	35.7	24.2
7	76.6	153.9	49.8	35.2	155.6	22.6	22.4	143.5	15.6	30	157.4	19.1	26.8	15.6
8	51.6	151.6	34	25.1	153.4	16.4	31.1	144.6	21.5	33.4	146.8	22.8	23.7	7.4
9	64.5	138.2	46.7	40.4	146	27.7	53.8	148.6	36.2	36.2	138.8	26.1	34.2	9.5
10	74.6	152.8	48.8	75.8	151.5	50	48.3	146.7	32.9	51	148.5	34.3	41.5	9.2
													34.7	
													6.9	

Appendix B. Statistical Analysis

I. 2-way ANOVA Percent Porosity

Descriptive Statistics

Dependent Variable: POROSITY

FLOW	COMP	Mean	Std. Deviation	N
cured	bulk	.340081	.188344	10
	inc	1.239014	.750086	10
	Total	.789547	.704248	20
uncured	bulk	.109685	7.99821E-02	10
	inc	.820948	.641223	10
	Total	.465317	.575260	20
Total	bulk	.224883	.183855	20
	inc	1.029981	.712226	20
	Total	.627432	.655590	40

Tests of Between-Subjects Effects

Dependent Variable: POROSITY

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7.621(a)	3	2.540	10.005	.000
Intercept	15.747	1	15.747	62.016	.000
FLOW	1.051	1	1.051	4.140	.049
COMP	6.482	1	6.482	25.527	.000
FLOW * COMP	8.805E-02	1	8.805E-02	.347	.560
Error	9.141	36	.254		
Total	32.509	40			
Corrected Total	16.762	39			

a R Squared = .455 (Adjusted R Squared = .409)

II. 2-way ANOVA Percent Microleakage

Descriptive Statistics

Dependent Variable: LEAKAGE

FLOW	COMP	Mean	Std. Deviation	N
cured	bulk	34.710	6.907	10
	inc	75.611	6.179	9
	Total	54.084	21.933	19
uncured	bulk	43.300	13.484	10
	inc	52.210	11.947	10
	Total	47.755	13.215	20
Total	bulk	39.005	11.320	20
	inc	63.295	15.246	19
	Total	50.838	18.040	39

Tests of Between-Subjects Effects

Dependent Variable: LEAKAGE

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	8711.525(a)	3	2903.842	27.802	.000
Intercept	103053.518	1	103053.518	986.647	.000
FLOW	533.600	1	533.600	5.109	.030
COMP	6035.222	1	6035.222	57.782	.000
FLOW * COMP	2489.427	1	2489.427	23.834	.000
Error	3655.687	35	104.448		
Total	113164.630	39			
Corrected Total	12367.212	38			

a R Squared = .704 (Adjusted R Squared = .679)

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